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Performance demonstration and evaluation of the synergetic application of thermochromic window and phase change material in passive buildings

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Abstract

As two of the most popular energy efficient materials, vanadium dioxide (VO_2) glazing and phase change material (PCM) were associated together for the first time. The synergetic application performance was demonstrated in a full-scale passive room and evaluated via Energy Saving Index (ESI). ESI, a novel and concise index, can be used to evaluate the passive application performance of materials or components from an energy standpoint and characterize the performance of a passive building material or component from a common standpoint. The results showed that the synergetic ESI was higher than the solo ESI of VO_2 glazing or PCM, which means that the synergetic application of VO_2 glazing and PCM could make further improvement on the thermal comfort degree of a passive room.

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Keywords: synergetic application; vanadium dioxide glazing; phase change material; performance evaluation; Energy Saving Index

1. Introduction

With appropriate energy efficient design, a passive building has the potential to minimize its operating energy consumption, as they can make full use of renewable energy (solar energy in most cases). Improvement on the building envelops (divided into two types generally: transparent one and non-transparent one) is the key issue to achieve a passive building. Current researches are mainly focused on particular materials or components of a single envelope type. However, application from a single type cannot meet the demand of both energy efficiency and thermal comfort, which indicates the necessity of association of materials or components belonging to different envelope types.

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Vanadium dioxide (VO_2) [1-3] and phase change materials (PCM) [4-6] are two of most widely studied energy efficient materials, and can be integrated into the non-transparent and the transparent building envelops, respectively. In this work, these two kinds of materials were associated together for the first time to improve the thermal comfort degree of a passive building.

2. Performance demonstration

The demonstration of the synergetic application was conducted in Testing and Demonstration Platform for Building Energy Research locating in the campus of University of Science and Technology of China. The platform contains two identical testing rooms: Room A and Room B. During the demonstration, one room can be set as an experiment unit by adopting a building component or material that needs to be demonstrated, while the other one can be set as a control. More information about the platform can be found in our previous work [7].

The VO_2 film was provided by Shanghai Institute of Ceramics, Chinese Academy of Sciences, which has been solo demonstrated in the platform. The phase transition temperature of the VO_2 particles on the film is $41.3\ ^{o}C$. The spectral transmittance and other information on the film has been given before [7]. The shape-stabilized phase change material was provided by Peking University, which also has been solo demonstrated. The phase transition temperature peak of PCM is about $38.8\ ^{o}C$, and its heat of fusion is about 101 J/g. Further information on PCM can be seen in the previous work [8].

To demonstrate the synergetic application of these two materials, Room A and Room B of the platform were set as the experimental group and the control group, respectively. For Room A, the VO_2 film was pasted on the outside surface of the exterior pane of the double glazing window. While the PCM plates were laid over the floor and then covered with thin steel plates. For each room, six thermal resistors were arranged at different depths and altitudes of the indoor space to obtain an average valve of the indoor air temperature. The rooms were in the passive mode and their indoor air temperature was measured and recorded to contrast the performances.

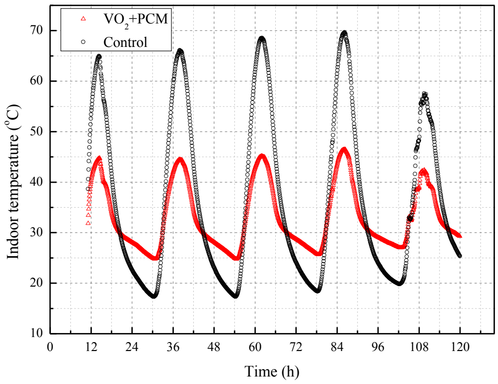

Fig. 1. Comparison of the indoor temperature.

The demonstration began on October 2nd, 2013, and lasted for 5 days. The comparison of the indoor temperature is shown in Fig. 1. It can be seen that the indoor temperature of the room with VO_2 and PCM is much lower than that of the counterpart at daytime, while the former is higher than the latter at night. For Room B without the adoption of passive building materials, the indoor temperature could rise to about $70\ ^{o}C$ as a result of the large area ratio of window to wall. However, the VO_2 film, which hindered solar radiation transmitting into the room through the window, acted as the first barrier to the high indoor temperature for Room A at daytime. And the second barrier was the PCM plates which absorbed the entered heat with its large latent heat capacity. The synergetic application of VO_2 and PCM brought indoor temperature to a much acceptable level by a decrease of about 25 °C . After the sun set, the heat stored in the PCM plates was released as the temperature of the indoor air was lower than that of the plates, which leaded to higher indoor temperature in Room A at night. The demonstration indicates that the synergetic application of VO_2 and PCM is an effective method to improve the thermal comfort degree of the building with glass curtain walls.

3. Further discussion

The meteorological data (solar irradiation, ambient air temperature, wind speed, etc.) during the demonstration has been measured and recorded, and can be used as the input of BuildingEnergy to simulate the indoor temperature variations of Room A and B. BuildingEnergy is a validated building modeling software which has been used in our previous work [7, 8]. Although the solo application performances of VO_2 and PCM have been demonstrated respectively. They cannot be compared directly as the meteorological conditions were different. They need to be simulated via BuildingEnergy with the meteorological data during the synergetic demonstration.

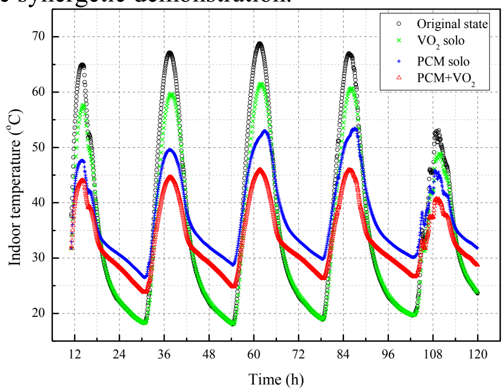

Fig. 2. Simulated indoor temperature variations with different building materials.

Fig. 2 shows the simulated indoor temperature states with different building materials, in which the state of Room B was described as the original state to facilitate the presentation. It can be seen that indoor temperature state with VO_2 solo is lower than the original one only at daytime. The state with PCM solo is lower than the original one at daytime due to the heat absorption, and higher than the original one at night due to the heat release. For a passive building, the solo adoption of these two materials was effective to improve the thermal comfort degree to some extent. But their limitations were also obvious: the effect of VO_2 solo was modest at daytime and the indoor temperature at night with PCM solo was raised undesirably. While the synergetic performance of VO_2 and PCM showed a compromise of the solo advantages and limitations: the state with synergetic application was lower than both of the states with solo applications and the undesirable temperature rise was also mitigated.

With a graph like Fig. 1 or Fig. 2, the performance application can be evaluated by the comparison of the indoor temperature states. However, the temperature difference varies with time, which makes such an index not so concise. In this work, Energy Saving Index (ESI) will be used to evaluate the application performance. Detailed definition of ESI can be seen in our previous work [8]. ESI can be used to evaluate different kinds of passive building components or materials from a common standpoint of energy consumption.

Corresponding ESE in Fig. 2 were obtained via BuildingEnergy. On the basis of these ESE values, ESI of VO_2 solo, PCM solo and VO_2 +PCM synergetic is 0.246, 0.105 and 0.336, respectively. All of the ESI values are positive, which means that the applications of these materials can improve the thermal comfort degree in a passive building. By comparison with the original state, the indoor temperature states with PCM were lowered at daytime and raised at night. It means that the application of PCM has both the negative and positive effects on the thermal comfort degree. However, the application of VO_2 has only the positive effect. Hence the adoption of VO_2 has a better comprehensive performance than that of PCM, i.e., the VO_2 solo application has a higher ESI than the PCM solo one. The synergetic application has the highest ESI and has a better performance than the solo application.

4. Conclusion

Two typical energy efficient building materials, VO_2 and PCM, were associated in a passive building. Their synergetic application performance was demonstrated in a full-scale passive room. With ESI as the evaluation index, the synergetic application was compared with the solo applications of VO_2 and PCM. The results showed that the synergetic application could further improve the indoor thermal comfort degree on the basis of the solo application and had the highest ESI among these applications.

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Biography

Dr. Hong Ye is an associate professor at department of thermal science and energy engineering, University of Science and Technology of China. Dr. Ye's research interests are in the areas of heat transfer, application of solar energy, building efficiency, measurement of thermal properties and thermophotovoltaic (TPV) system.